

Advances in the endovascular treatment of intracranial arteriovenous malformations

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The three treatment options for intracranial arteriovenous malformation are resection, endovascular embolization, and stereotactic radioneurosurgery. In rare cases, the malformation can be eradicated using only one of these options; most cases require a combination of the options, even all three. The most recent advances have been in interventional neuroradiology with the introduction of high-definition 3D imaging and hyperselective intranidal endovascular embolization using microcatheters and microguidewires, giving marked advantages in terms of rapidity, efficacy, and safety. Nidal devascularization is now much improved, as shown by the increased interval between embolization sessions, while high-field functional magnetic resonance imaging plays a valuable role in the preembolization work-up and postembolization follow-up.

Various classifications have been proposed for intracranial arteriovenous malformation (AVM), based on specific architectonic and topographic patterns or, more recently, on specific aspects of neurosurgical ther-

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apy.¹⁻³ Recent technical developments in interventional neuroradiology, in particular the high definitions now achievable, provide a much more detailed analysis of the anatomic and functional features of AVM, thereby enhancing the precision, efficacy, and safety of this management option.

Definition, classification, and epidemiology

AVM is the most common congenital vascular malformation and reflects the persistence of the original communication between the arterial and venous capillary networks. The structure of each AVM consists of afferent arteries, a central nucleus (nidus), and a halo of dilated efferent veins. Each element can vary in number, size, and flow. The arterial system is mainly pial, although dural afferents can be found at particular sites in the base of the brain (posterior fossa). Most cases of AVM (80% and 93%) are supratentorial, mainly in the cortex and sub-cortex. However, deep-seated or two-site lesions may be subtentorial and, although scarcer, these are potentially much more severe, due to the adjacent parenchyma.

AVM used to be thought infrequent (0.14% in the USA), but more recent studies show a higher prevalence, due to readier diagnosis by computed tomography and magnetic resonance imaging (MRI).⁴ Spetzler and Martin⁵ proposed a predictive approach to severity and treatability based on site (with particular reference to functional areas of encephalon), size, venous drainage (including venous volume), and efferent blood flow.

Presentation can be differentiated into a pediatric pattern, characterized by intracranial hemorrhage often preceded by central nervous system abnormalities, and an adult pattern of seizure or chronic headache. Although the risk of hemorrhage is generally seen as slight, recent studies show that it is actually at least as high as in aneurysm.⁶ The theoretical risk of cerebromeningeal hemorrhage is 2% to 3% per year, with a risk of death during rupture of 10%, increasing after each hemorrhage. The probability of a

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second bleed is 6% in the first year, and increases by 4% per year. Even in the absence of hemorrhage, morbidity and mortality are higher than in individuals without AVM. For these reasons, early diagnosis, if possible before a hemorrhagic event, is fundamental: Brown et al found an intracranial hemorrhage rate of 18% over a mean 8-year follow-up in 168 patients with clinically unruptured AVM.⁷

Endovascular treatment: embolization objectives

There are three treatment options for AVM: resection, stereotactic neurosurgery, and embolization or endovascular surgery, alone or in sequential combination. This multimodal approach forms the basis for defining treatment objectives and planning follow-up, the aim being the effective eradication of the AVM. The options are complementary, and the decision to use one or another must be flexible and informed by the clinical particularities and treatment techniques available.⁸ Maximum accuracy is required in assessing the treatment objectives. These include the control or eradication of persistent headache, seizures, and hemorrhagic risk, and the delay or arrest of progressive neurologic deficit. The decision process is subject to the following guidelines:

- Multidisciplinary consultation between neurosurgeons (conventional and stereotactic) and interventional neuroradiologists
 - Definition of treatment outcome measures in terms of the clinical presentation
 - Appreciation of the gap between technical feasibility and the target of complete cure
 - Sequential implementation of treatment options
 - Flexibility based on the clinical features, morphology, and the latest developments in endovascular techniques
- Objectives, procedures, and treatment sequences vary but broadly comprise:
- Total eradication of the AVM by one of the methods (mainly resection and embolization)
 - Pretherapeutic debulking palliative embolization to reduce arterial pedicle number, nidus size, and venous drainage volume before resection or stereotactic neurosurgery
 - Clinically palliative embolization to decrease seizure frequency and severity in massive AVM
 - Palliative embolization for deep AVM fed by lenticulostriate perforating arteries causing vascular steal with progressive neurologic deficit

Hypersensitive intranidal catheterization: microcatheters and microguidewires

Hypersensitive multipedicular catheterization identifies the afferent arteries, a variably compartmentalized nidus, and generally dilated efferent veins (*Figure 1*). However, analysis of these morphologic elements may fail to differentiate clearly between the nidus and the often grossly dilated veins. What is required is a hypersensitive approach to the intranidal compartments themselves, since it is their destruction, with the resulting decrease in venous flow, which is the prime target of embolization. Using a 70- μ microguidewire (Sorcerer), the tip of a flow-dependent microcatheter (Magic 1.2F) can be advanced through every arterial convolution to reach the nidus core (*Figure 2*). The nidal angioarchitectonics can then be demonstrated in high definition by in situ opacification, followed by the introduction of a liquid embolus (*N*-butyl cyanoacrylate + iodopamidol [Lipiodol®]) for safe and maximally effective embolization (*Figure 3*).^{9,10} The aim is compartmental obliteration, in addition to reducing the number of afferent arteries and/or narrowing their lumen, thereby decreasing efferent volume and flow. The effect may be near-immediate, but postembolization review sometimes reveals that intranidal thrombosis is delayed for several months.

Conclusion

Maximal accuracy is essential in the evaluation of each AVM component. Intranidal treatment of AVM has benefited greatly from the recent technical developments in both neurovascular imaging (definition, acquisition speed, and 3D reconstruction) and the microhardware of endovascular intervention (microguidewire and microcatheter). Procedures are now faster, safer, and more effective, with longer intervals between embolization sessions, while pre- and postprocedural review of brain parenchyma using functional MRI and cerebral analytic spectroscopy has played a key role.^{11,12} Further technical advances will soon transform the quantification of management decisions, with increasingly accurate analysis of supra- and infratentorial sites, and the ability to adapt therapy to the changing morphology and topography of individual AVMs. □

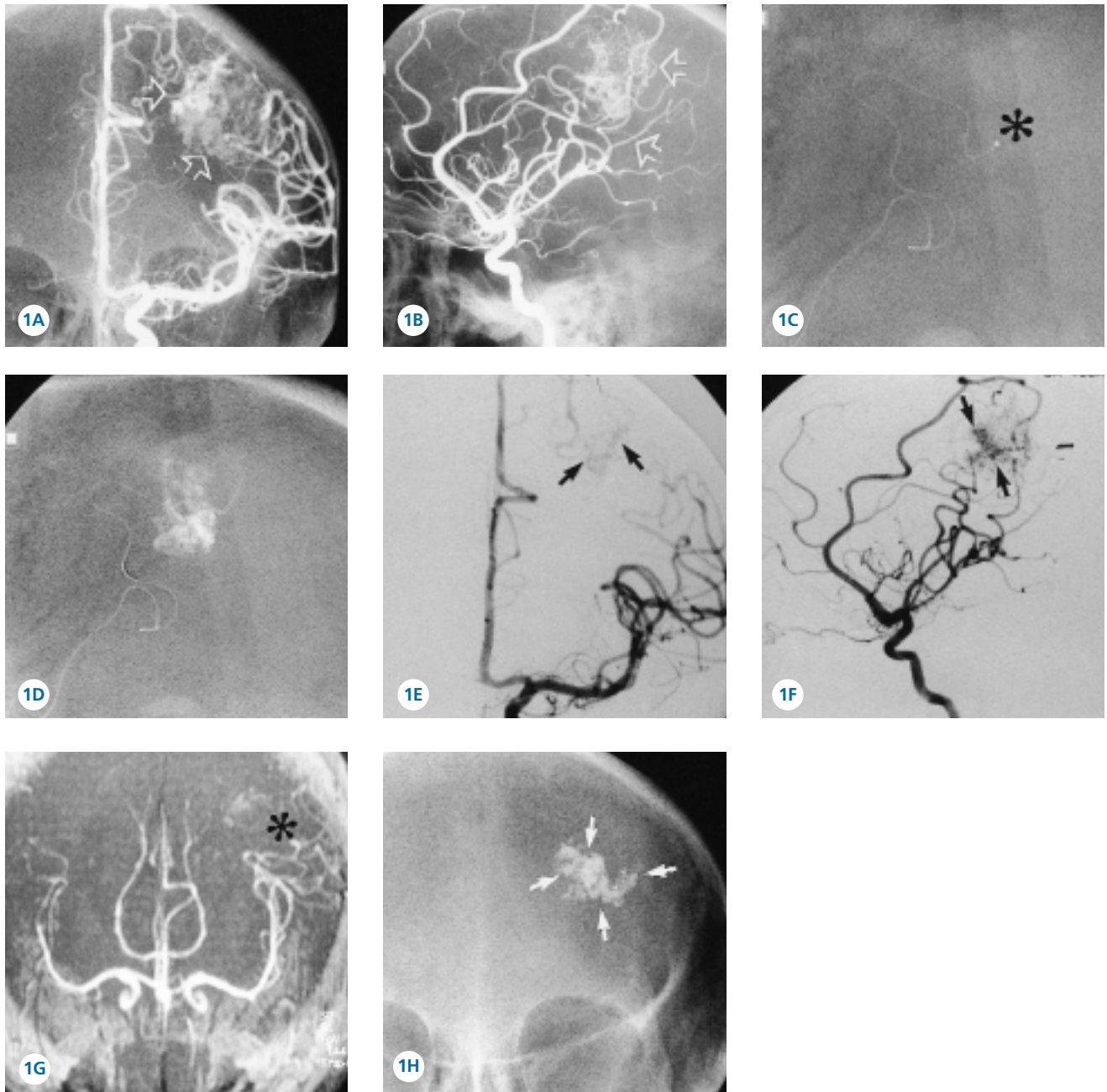


Figure 1. Embolization of a huge left parietal Rolandic arteriovenous malformation. **A,B:** Preembolization opacification, arrows indicate opacification by both anterior cerebral and sylvian artery feeders. **C,D:** Hyperselective intranidal catheterization using a Magic 1.2 F microcatheter (asterisk). **E,F:** Immediate postembolization control showing small residual vessels (arrows). **G,H:** One-year follow-up after stereotaxic neurosurgery (G) using magnetic resonance angiogram control (asterisk) and (H) nidus casting by *N*-butyl cyanoacrylate embolization (arrows).

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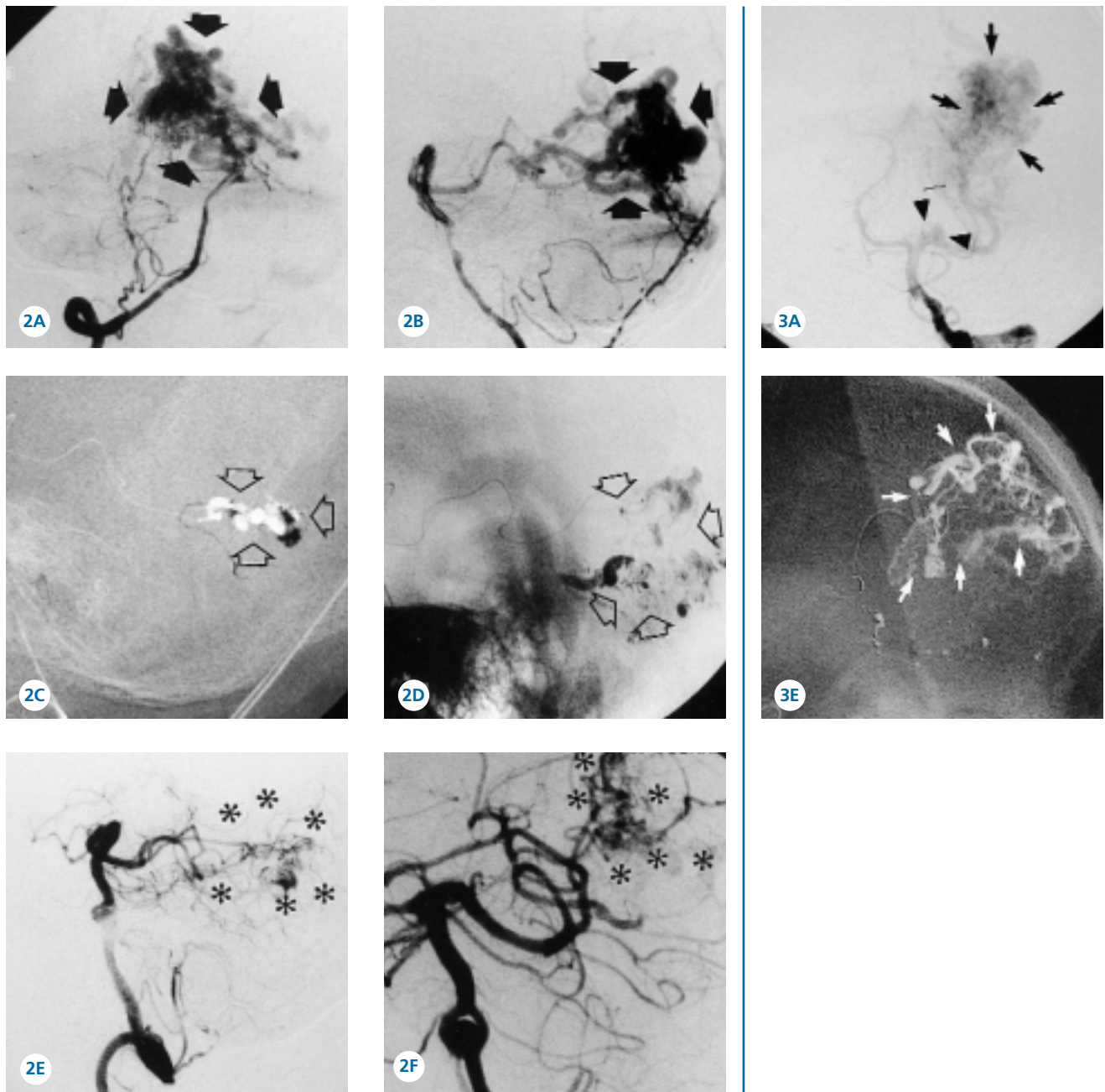


Figure 2. Embolization of an occipital arteriovenous malformation with a dural fistula. **A,B:** Preembolization angiogram showing the nidus of the arteriovenous malformation (arrows) opacified by the left posterior cerebral artery and the posterior meningeal artery. **C,D:** Hyperselective intranidal catheterization and embolization (arrows) with an *N*-butyl cyanoacrylate/Lipiodol® mixture. **E,F:** Immediate postembolization review showing complete embolization of the arteriovenous malformation (asterisks).

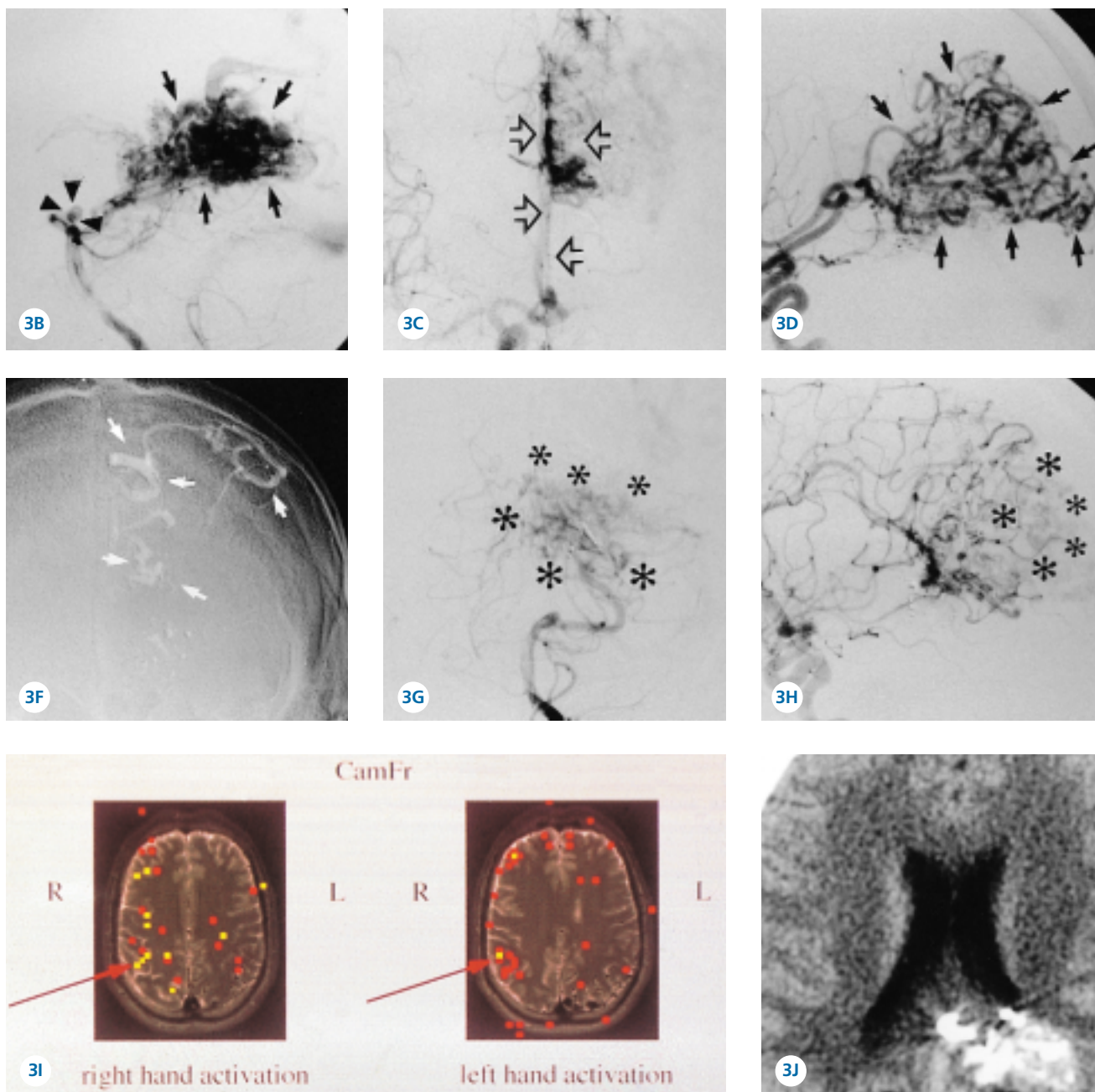


Figure 3. Embolization of a parietal Rolandic and occipital arteriovenous malformation. **A,B:** Opacification of the occipital part of the arteriovenous malformation by left vertebral artery catheterization, demonstrating the nidus and the draining veins (arrows) and a high-flow aneurysm located in the initial portion of the left posterior cerebral artery (arrows). **C,D:** Parietal Rolandic section of the arteriovenous malformation opacified by the left sylvian artery (main feeders) and the right and left cerebral artery (arrows). **E,F:** Hyperselective intranidal catheterization by a Magic 1.2 F microcatheter and embolization with an *N*-butyl cyanoacrylate/Lipiodol® mixture (arrows). **G,H:** Three-month follow-up angiogram showing highly significant reduction of the two parts of the arteriovenous malformation and significant reduction of the high-flow aneurysm (asterisks). **I,J:** Demonstration of the plasticity and cerebral capacity of adaptation to a specific situation in relation to a left arteriovenous malformation. Functional 3-Tesla magnetic resonance image showing activation of the left and right Rolandic motor centers with the appropriate stimulation (**I**). Postembolization computed tomography showing the *N*-butyl cyanoacrylate/Lipiodol® mixture in the middle of the nidus (**J**).

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Avances en el tratamiento endovascular de las malformaciones arterio venosas intracraneales

Las tres alternativas de tratamiento para las malformaciones arterio venosas intracraneales son la resección, la embolización endovascular y la neurocirugía estereotáxica. En raros casos la malformación puede ser erradicada utilizando sólo una de estas opciones; la mayoría de las veces se requiere de una combinación de alternativas, incluso de las tres juntas. Los avances más recientes se han producido en la neuroradiología intervencionista con la introducción de las imágenes en tres dimensiones de alta definición y la embolización endovascular del interior del nido, hiperselectiva, utilizando microcatéteres y cables microguías, lo que produce ventajas significativas en términos de rapidez, eficacia y seguridad. La desvascularización del nido está ahora más perfeccionada, lo que se expresa en el aumento del intervalo de tiempo entre las sesiones de embolización. Por su parte las imágenes de resonancia magnética funcional de alta resolución juegan un papel valioso en la preparación pre-embolización y el seguimiento post-embolización.

Progrès dans le traitement endovasculaire des malformations intracrâniennes artérioveineuses

Les progrès récents en neuroradiologie interventionnelle ont permis la réalisation d'abord endovasculaires hypersélectifs et intranidaux concernant l'étude des malformations artérioveineuses (MAV) intracrâniennes. Trois possibilités thérapeutiques demeurent envisageables en ce qui concerne le traitement des MAV: la microneurochirurgie classique, la chirurgie endovasculaire ou embolisation et la radio-neurochirurgie stéréotaxique. Si rarement, une seule de ces méthodes peut suffire à éradiquer totalement une malformation artérioveineuse, le plus souvent c'est l'association de deux voire trois de ces possibilités qui sera retenue. La place de l'embolisation n'a cessé de se développer et les progrès concernant l'utilisation de microcathéters et de microguides permettent un abord plus précis, plus rapide, donc plus sécurisant pour le patient. La dévascularisation nidale ainsi obtenue s'avère de meilleure qualité, son efficacité doit s'apprécier dans la durée entre deux séances d'embolisation et l'application des techniques d'IRM à haut champ apparaît d'une utilité incomparable tant dans le bilan pré-opératoire que dans le suivi des patients.

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